JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2008, **90,** 113–124 NUMBER 1 (JULY)

AN INEXPENSIVE AND AUTOMATED METHOD FOR PRESENTING OLFACTORY OR TACTILE STIMULI TO RATS IN A TWO-CHOICE DISCRIMINATION TASK

IVER H. IVERSEN

UNIVERSITY OF NORTH FLORIDA

An inexpensive and automated method for presentation of olfactory or tactile stimuli in a two-choice task for rats was implemented with the use of a computer-controlled bidirectional motor. The motor rotated a disk that presented two stimuli of different texture for tactile discrimination, or different odor for olfactory discrimination. Because the solid olfactory stimuli were placed outside the chamber in metal pods with a mesh at front for odor sampling, ''washout'' of odors between trials was not necessary. To avoid differential auditory cues from motor rotation, the stimuli were arranged such that on each trial the motor always rotated exactly one quarter revolution (in 1 s), left or right, to present the next stimulus at trial start. To illustrate the use of the equipment, 2 rats were trained on tactile discrimination and 2 rats on olfactory discrimination. The rats sampled the stimulus on the disk through a port on the back wall by sniffing at it (olfactory) or touching it (tactile). The task was a go-left/go-right discrimination with the stimulus on the disk being discriminative for which lever provided reinforcement. The rats reached a stable level above 90% correct after 21 and 32 training sessions for tactile and olfactory discrimination, respectively. The article outlines how the equipment was constructed from low-cost components. Inputs from and outputs to the equipment were implemented through the parallel port of a personal computer without the use of a commercial interface board. The method of automated and low-cost presentation of olfactory or tactile stimuli should be of use for a variety of experimental situations such as matching-to-sample and cross-modal discrimination.

Key words: olfactory discrimination, tactile discrimination, two-choice task, automated stimulus presentation, bidirectional motor, rats

---

Discriminative stimuli for rats are customarily visual, and operant behavior can readily be brought under discriminative control by visual stimuli (e.g., Skinner, 1938). Auditory stimuli have been used on occasion, but to obtain reliable discriminative control care must be taken in the spatial location of the stimulus with respect to the location of the operandum (e.g., Neill & Harrison, 1987); the location of a visual stimulus is less critical, albeit there are some notable exceptions (e.g., Henton & Iversen, 1978). In basic research on discriminative or conditional stimulus control, relatively few experiments reported within the pages of *Journal of the Experimental Analysis of Behavior* have used stimuli from other modalities such as olfactory or tactile stimuli. For olfactory stimuli, two basic methods are identified. One method presents ambient odors that ''flood'' the chamber so that they are detectable from any location of the subject within the chamber. For example, Cohn and Weiss (2007) used an automated procedure to present ambient odor vapors to rats, and the method required elaborate ventilation to eliminate odors lingering in the chamber between trials. A second method presents odors localized, so that the subject has to move to that location to sample the odor. Mihalick, Langlois, Krienke, and Dube (2000) trained mice to dig in containers of sand mixed with solid, ground odorants; stimulus presentation and removal was manual, and ventilation of the chamber was not required because the odorants were removed between trials.

Several fully automated methods for olfactory discrimination have been described in the literature. In an impressive early study, Henton (1969) presented airborne odorous stimuli to pigeons for threshold determinations of olfactory sensitivity using a conditioned suppression task. The odorous vapor passed through a glass breathing chamber that also housed the operandum and grain hopper; to distinguish stimulus from nonstimulus periods, the glass chamber was ventilated between trials. An automated go/no-go method, based on early work by Slotnick and Katz (1974) called the

---

Two 30-s video clips showing (1) a close up of the rotation of the disk with odor pods and the odor sampling response made by a rat; and (2) performance on the full odor-discrimination task, will be available *in the supplemental section of this article* at PubMedCentral.

Address correspondence to Iver Iversen, Department of Psychology, University of North Florida, 1 UNF Drive, Jacksonville, FL 32224-7699 (e-mail: iiversen@unf.edu).

doi: 10.1901/jeab.2008.90-113

''computerized olfactometer'', is apparently very popular in contemporary neuroscience. Rats sample a vaporized odor in a port, and in some experiments the rats stay or leave the port depending on the odor (e.g., Abraham et al., 2004) and in other experiments they withdraw from the port, and depending on the odor either make a response or refrain from making a response at another location, usually at the reinforcer delivery site (e.g., Sokolic & McGregor, 2007). Also using automated equipment, rats were trained on discriminations of airborne odors in a matching-to-sample task where two odors, same or different, were presented successively; rats remained at the stimulus location and responded in a go/no-go fashion for water reinforcement (Lu, Slotnick, & Silberberg, 1993). Lionello-DeNolf and Mihalick (2006) described an elaborate and fully automated discrimination procedure with rats for presentation of airborne olfactory stimuli at up to five chamber locations. With this method, several different odors could be presented within a session, but clean air had to be pumped through the system as well. These automated tasks all require elaborate automated within-session ventilation and cleaning methods to avoid lingering or mixing of odor cues in the equipment.

Tactile discrimination research is also relatively rare in the behavior analysis literature. In an innovative and automated study of generalization of tactile stimuli with horses as subjects, Dougherty and Lewis (1993) used solenoids to present the tactile stimuli (tapping of the skin) at different locations to the horses' backs. In a particularly creative study, Domjan, Miller, and Gemberling (1982) presented cookies in two different shapes to monkeys in darkness, and using taste-aversion learning, a discrimination was established between the two shapes. Rats have been trained in an automated discrimination task to reach through a port to touch sticks of different thickness or spatial orientation (e.g., Ballermann, Tompkins, & Whishaw, 2000). Rats have also been trained in automated go-left/go-right tasks to detect with their whiskers whether an aperture was narrow or wide (e.g., Krupa, Wiest, Shuler, Laubach, & Nicolelis, 2004). Tactile discriminations with rats have also been implemented by varying the texture of floorboards (e.g., Xerri, Bourgeon, & Coq, 2005).

Whereas a variety of olfactory and tactile discrimination tasks are available, they either require elaborate and costly equipment to control stimulus presentation and within-session cleaning (for olfactory stimuli) or rely on manual presentation of the stimuli. The purpose of the present experiment was to develop a low-cost and fully automated method for presentation of olfactory or tactile stimuli at a specific chamber location for two-choice discrimination tasks with rats. In particular, a method was sought for olfactory stimuli that would not require cleaning of the air within the chamber or the delivery system between trials. The stimulus-delivery apparatus is versatile and accommodates either olfactory or tactile stimuli and is controlled in the same manner by the program from the computer. Olfactory stimuli were solid and were encapsulated in pods with a mesh that faced the rat for sampling. Tactile stimuli were textured surfaces that faced the rat for sampling. A unique feature of the method is that the rats are not passively exposed to the stimuli, as when a tone is turned on regardless of the subject's behavior or location. Instead, the subject initiates a trial by sampling the stimulus through a port in one chamber wall. The subjects are only exposed to the stimuli during this sampling period. The method is intended for research where the basic issue is discriminative control of behavior by olfactory or tactile stimuli.

METHOD

Subjects

Four female, Long Evans rats (Harlan, Indianapolis, IN) were maintained at 85% of their free-feeding body weights. The rats were weighed daily and housed individually in wire-mesh cages with continuous access to water. The rats were about 5 months old at the start of the experiment. Supplemental chow was provided 1 hr after each daily session. The colony was maintained on a 12:12-hr light/dark cycle.

Previous training history. The rats had a previous training history that was compatible with and a prerequisite for the present experiment. Each rat had acquired a visual discrimination such that when the light over the left lever turned on, a press on the left lever produced a food pellet. Similarly, when the light over the right lever turned on, a press on the right lever produced a food pellet. Trials with either light lit were separated by variable intertrial intervals averaging 60 s. Presses on either lever in the absence of the lights prolonged the intertrial intervals by 15 s. The resulting performance was that the rats would promptly respond to the lever under the light that was lit and practically never respond to a lever under a light that was off.

Apparatus

A standard rodent-test apparatus from Med Associates (ENV-008) was used. It measured 30.5 cm wide, 24.1 cm deep, and 21 cm high. The front wall had two 4.8-cm wide levers (ENV-110m) situated 7.5 cm from the grid floor and 3 cm from the edge of the feeder opening and required a force of 0.2 N for operation. The 5.1 × 5.1 cm feeder opening (ENV-110m) was placed 1.5 cm above the grid floor and centered on the wall between the levers. A Med Associates standard pellet dispenser (ENV-203m) delivered 45-mg Noyes standard precision pellets into the feeder. Pellet delivery was accompanied by a 200-ms ''beep'' from a Sonalert Buzzer (Model SCG28) located underneath the pellet feeder outside the test chamber. A 2.5-cm diameter white light (ENV-221m) was located 5 cm above each lever.

Because the purpose of the research was to design new apparatus, the experiment was conducted on a tabletop so that the experimenter could visually identify possible problems with the equipment during sessions. Hence, no masking noise or visual shields were used during sessions, except for the removal of ambient light during test sessions (see below). The computer that controlled the experiment was located about 1 m to the right of the equipment. Performance was videotaped and photographed during selected sessions.

Stimulus-sampling port. For tactile discrimination, the back wall had a 4-cm wide, 1-cm high opening, 8 cm from the floor and centered between the side walls. The subject sampled the stimulus by inserting a paw through the opening and placing it on the stimulus surface. Paw insertion was detected by an infrared phototransistor (RadioShack 276-145) when the beam from an infrared light-emitting diode (LED) (RadioShack 276-143)

A

B

Fig. 1. Photographs of the equipment. Tactile stimuli are cutouts of thin, textured styrene plastic sheets that are glued to an 8-cm disk (A). The disk rotates, left or right, by a bidirectional motor under the disk. The upper-right corner in A shows the rectangular opening in the back wall, the stimulus-sampling port, through which the subject touches the disk surface. Solid olfactory stimuli are encapsulated in metal pods with a mesh at front made from modified faucet aerators. The pods are stabilized on the rotating disk (B).

was interrupted by the paw (these items are less than $3 each—all prices are given as of October, 2007). The phototransistor and the LED were situated on the outside of the back wall, 1 cm from the wall and 5 cm apart across the opening. The LED was powered directly by a 1.5-V battery. The phototransistor was connected to a PhotoMos relay (NAIS AQZ102, $7.50) for input to the computer's parallel port. Interruption of the infrared beam was thereby detected by an Input statement in the control program. The appendix in Iversen (2002) described some programming routines for handling Input and Output via the computer's parallel port.

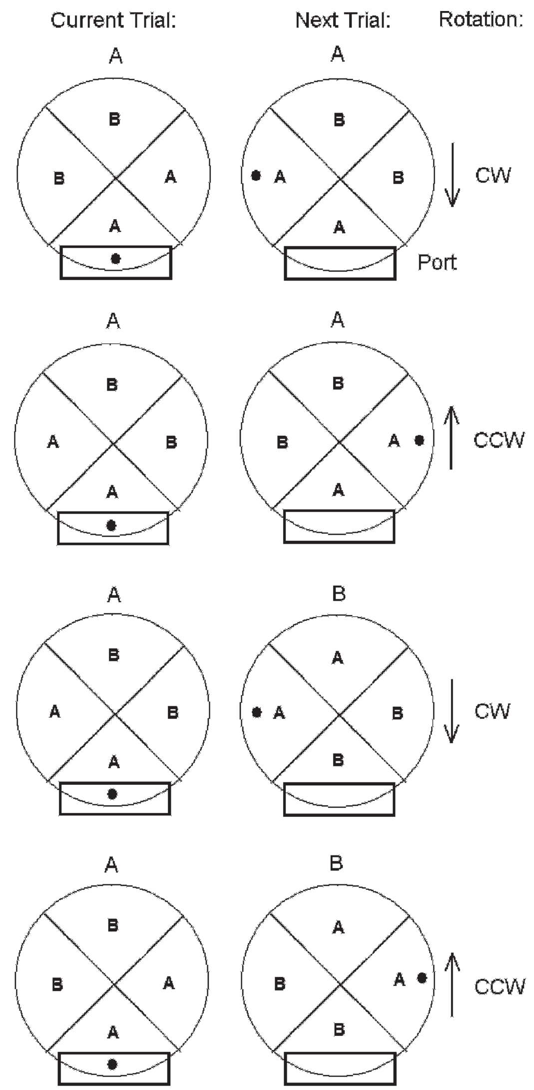

Fig. 2. Schematic illustration of the logic of the arrangement of the stimuli on the rotating disk. The disk holds two different pairs of identical stimuli placed adjacent to each other, symbolized as AA and BB. The rectangle represents the stimulus-sampling port. The motor always makes one quarter turn for each trial either clockwise (CW) or counterclockwise (CCW). A new trial presents either the same stimulus as on the previous trial (the other member of the identical pair) or the different stimulus. To facilitate inspection of this display, a dot indicates the stimulus that faced the port on a current trial and where that stimulus goes on the next trial (left or right). In the top display, the current trial has an A stimulus and the next trial also has an A stimulus; because of the position of the stimuli, the motor makes one quarter revolution in a clockwise turn. In the next display, the current trial also has an A stimulus and the next trial is an A stimulus as well, but because of the different position of the disk, the disk rotates counterclockwise. Notice that across examples the direction of rotation is not correlated

←

with stimulus type. The figure shows only 8 of the possible 16 configurations of stimulus position and disk rotation from a current trial to the next trial.

For olfactory stimuli, the back wall had a 1-cm diameter opening, 8 cm from the floor and centered between the side walls. The subject sampled the olfactory stimulus by placing the nose in the opening. Nose insertion broke an infrared beam across the opening directly on the outside of the back wall.

Bidirectional motor. A rotating disk was designed to present two pairs of either tactile or olfactory stimuli (stimuli are described below). The disk was attached to a bidirectional motor to form an automated stimulus-presentation unit. The motor (Dayton, Permanent magnet DC gear motor, Model 2L009, $49) was powered by a RadioShack Micronta-regulated 12 VDC power supply ($42); a 40-ohm power resistor was placed in series with the motor to adjust the rational speed to one revolution in 4 s. The motor was mounted on a 10 by 10 cm Plexiglas plate (2 mm thick) and supported by four legs made of Plexiglas tubes. The motor rotated an 8-cm diameter disk (4 mm thick) made of Plexiglas. The disk was glued to a 1.5-cm wide plastic tube that fitted over the 8-mm shaft that extended from the motor. The tube was affixed to the shaft by four screws. Figure 1A shows a picture of the rotating disk with tactile stimuli; each quarter of the disk was occupied by one member of two pairs of identical stimuli. The disk with the four odor pods is shown in Figure 1B.

Figure 2 shows a schematic of the logic of stimulus presentation and motor rotation from one trial to the next. The disk presented different pairs of identical stimuli, which are symbolized as AA and BB. One stimulus faced the stimulus sampling port (the stimulus from the current trial is marked by a dot to facilitate identifying its location after rotation). When a trial ended, the program determined whether the next stimulus should be the same or different. The motor turned clockwise (CW) or counterclockwise (CCW) to present either the same stimulus again (the other one from the same pair) or the different stimulus (one from the other pair). Figure 2 shows 8 of the possible 16 constellations of stimulus position and direction of rotation. Thus, for each trial, the motor always made exactly and only one quarter turn whether the stimulus on that trial was the same as or different from that on the previous trial. Also, the direction of rotation was not predictive of which stimulus would be presented next. The rationale behind this design of seemingly unnecessary motor rotation, when the next trial presents the same stimulus again, is that if the motor only operated when the stimulus changed on the next trial, then the sound of rotation might become a discriminative stimulus for switching to the other response and the absence of the motor sound might become a discriminative stimulus for making the same response again on the next trial. Hence, the motor always made a quarter turn, lasting 1 s, on each trial.

The direction of motor rotation was controlled by the polarity of the voltage supplied to the motor. A custom-made logic board composed of four PhotoMos Relays (NAIS AQZ102; $7.50 each) determined the polarity of voltage and hence the direction of rotation. These relays are simple optical switches (Common/Normally Open) powered directly from the output of the computer's parallel port. Thus, to control rotational direction, four output commands were used, one for each relay. The first two output commands sent ''plus'' and ''minus'' to the motor for clockwise rotation, while the next two output commands sent ''plus'' and ''minus'' to the motor for counterclockwise rotation. Figure 3 illustrates the diagram of the logic board. Each relay has four terminals; the bottom two terminals, close together, control the relay and are connected to the computer's parallel port. The top two terminals, wider apart, connect to the switch inside the relay. The output from the computer's parallel port (5 VDC) was sufficient to activate the PhotoMos relay, and no commercial I/O board was required. The motor turns clockwise when relays 1 and 4 are ON, and the motor turns counterclockwise and when relays 2 and 3 are ON. The motor is stationary when all relays are in the OFF position.

To enable perfect centering of the stimulus in the sampling port, the motor assembly was outfitted with stop flaps. For each quarter segment of the disk, a 1 × 1-cm plastic flap extended below the disk. These flaps passed through a groove with an infrared LED (RadioShack 276-143) and a phototransistor (RadioShack 276-145), as shown in Figure 4A. When the phototransistor was covered by the flap, the input to the control program read that the disk had reached the correct position, and the motor was therefore given a stop command. By this method, the stimulus was centered in the sampling port on all trials.

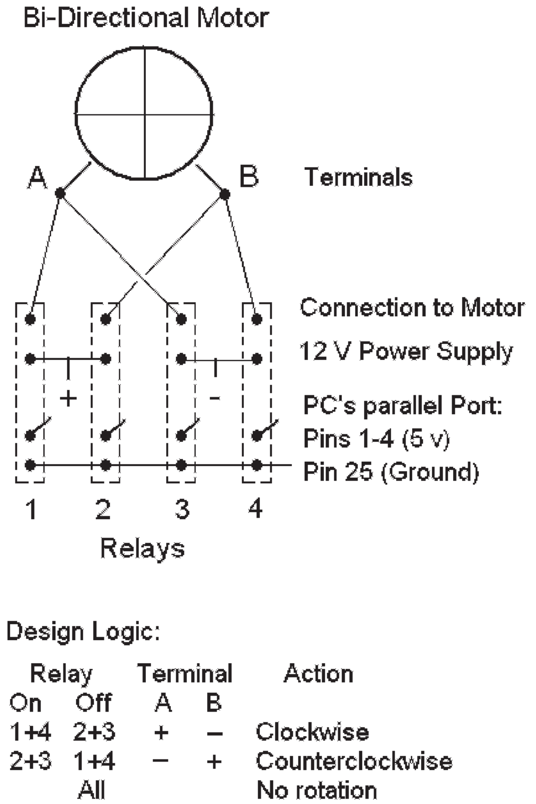

Fig. 3. Schematic of the logic board that controlled the direction of motor rotation. Four PhotoMos optical relays (indicated by perforated rectangles) were activated from the computer's parallel port. The relays were simple ON/OFF switches that controlled the polarity of the voltage to the terminals of the motor, indicated by A and B. With + at A and − at B (Relays 1 and 4 turned ON), the motor turned clockwise. Reversed rotation was obtained with − at A and + at B (Relays 2 and 3 turned ON). The motor did not operate when all four relays were switched OFF.

Figure 4B shows a photograph that illustrates the size of the stimulus-presentation unit, at left, relative to the size of the operant chamber; the pellet feeder is seen on the right.

Tactile stimuli. The tactile stimuli were made from a thin, textured styrene plastic sheet, which was cut to size by a pair of scissors. Such flexible plastic sheets are available in great variety in hobby stores (each less than

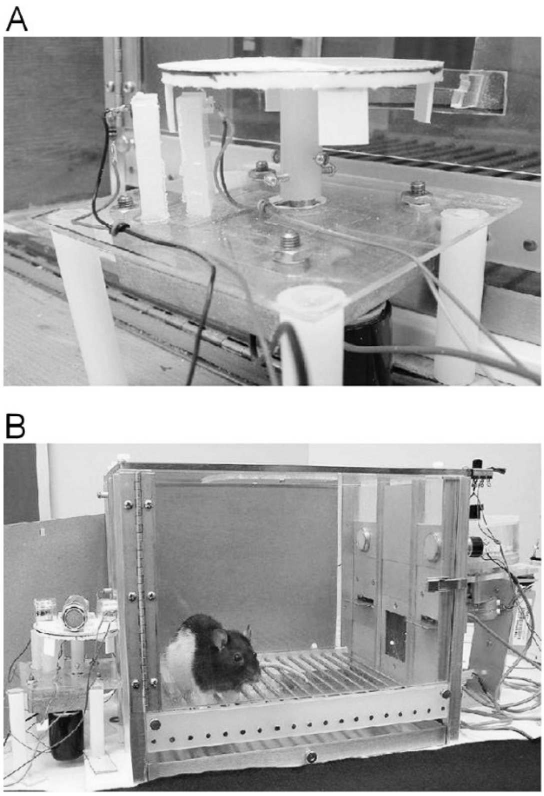

Fig. 4. Side view of the stimulus-delivery apparatus showing the four plastic flaps that extend under the disk to break an infrared light (upper left corner) when the disk reaches a location such that the stimulus is centered in the sampling port. Also visible is the center tube with four screws that connects the disk to the shaft of the motor (A). The motor is located under the large Plexiglas sheet, which is supported by four legs made of plastic tubing. Illustration of the full assembly of the stimulus-presentation apparatus (left) in proportion to the size of the rodent test chamber; the levers and the pellet feeder are to the right (B).

$10). For the present experiment, the selection of the pattern embossed into the plastic was arbitrary, and a simple ''clapboard siding'' pattern with 2-mm wide groves (0.2 mm deep) was chosen for its distinction to the touch by a human finger. The reverse side of the plastic sheet was smooth. The stimuli used were therefore a smooth surface versus a surface with evenly spaced groves. The custom-cut sheets were glued to the disk that was mounted on the bidirectional motor, as illustrated in Figure 1A.

Olfactory stimuli. The olfactory stimuli were selected for simplicity and distinction and consisted of two types of finely ground tea leaves from commercially available tea bags; the stimuli were fruit tea and British tea (Baslow Tea Company). The tea powder was placed in metal containers with a cardboard plug at one end and a fine metal mesh at the other end, which faced the stimulus-sampling port. The 2.2-cm diameter, 1-cm long metal containers were modifications of aerators from kitchen faucets (Dual Thread Aerator, Danco 36149B, $2). The various internal washers and plastic attachments were discarded, and the internal metal mesh facing the front was glued to the aerator. Odor pods were labeled on the back and rested on grooves on the rotating disk, as illustrated in Figure 1B, and affixed with tape. The pods were situated right behind the port, with only about 5 mm between the rat's nose and the metal mesh though which the rat sampled the odor. To keep the odors fresh, the odor pods were emptied every third session and replenished with tea from a freshly opened tea bag. The online supplemental video material (see author's note) features a 30-s clip showing rotation of the stimulus-presentation disk and sampling of the olfactory stimulus through the port.

Overview of the general flow of events. A program, written in QuickBasic, controlled the experiment. Stimulus presentation was quasirandom, with a maximum of four trials with the same stimulus in a row. The program kept track of which stimulus was presented on a given trial and which direction the motor should turn on a given trial. The motor turned following a lever press when the lights were lit. Thus, a rat always was situated by one of the levers when the 1-s rotation started. This arrangement prevented stimulus rotation while a rat engaged the stimulus-sampling port. For the first trial in a session, the experimenter started the session by pressing a key when the rat was facing away from the back wall.

The experiment had no defined intertrial period. Instead, the trial started when the rat sampled the stimulus through the port. Rats usually engaged the stimulus-sampling port a few seconds after motor rotation ended. When the infrared beam had been interrupted for 0.1 s for the olfactory stimulus and 0.3 s for the tactile stimulus (as a minimal sampling duration), the program presented a 200-ms, 1000-Hz tone through the speaker in the computer and either one or both lights above the levers were lit (depending on the training phase, see Procedure). Thus, the lights were lit after the sampling response had been initiated. When the rat pressed either lever, the lights turned off, the motor began to rotate for stimulus presentation for the next trial, and a pellet was presented if the rat had pressed the ''correct'' lever.

Procedure

Because each rat had previous experience in an identical test chamber (without the modification of the back wall), magazine training and lever press training were not necessary. The rats had been trained to press the lever under the light that was lit (see *Subjects*). This performance was reestablished in the new equipment in two 60-trial sessions with the previous training procedure. One addition to the previous procedure was that light onset was accompanied by the tone. The rationale for this addition was that rats would always be engaging the stimulus-sampling port when the lights turned on (as described above), and light onset behind the rat therefore might not be a very salient stimulus. The tone was audible regardless of the rat's location.

Tactile discrimination. For Rats 1 and 2, the task was tactile discrimination. The method of shaping by successive approximation (Gleeson, 1991) was used to train the rats to extend a paw through the opening in the back wall and touch the surface of the disk. Because stimulus control, by the lights above the levers, was firmly established prior to this experiment, the reinforcer used for shaping was to turn a light on above a lever (with the accompanying tone) and thereby setting the occasion for a lever press to be reinforced. First, merely touching the edge of the opening was reinforced in 5 trials. Then, extending the paw through the opening was reinforced in 10 trials. Thereafter, touching the surface of the disk was reinforced by the lights such that the left light plus tone turned on after touching the smooth surface, and the right light plus tone turned on after touching the rough surface. The experimenter observed the rats and pressed a key to enable light–tone onset after an appropriate touch response. Within one session both rats reliably touched the disk for approximately 0.5 s. The procedure was automated after this first shaping session. Each rat had to extend the paw through the port for a minimum duration of 0.3 s before one of the lights plus tone would turn on. After two sessions, the procedure changed to actual discrimination of the tactile stimuli. The only change made was that both lights plus the tone turned on simultaneously. The only stimulus that indicated which lever was correct was the tactile stimulus. Thus, even though the equipment did not detect an actual touch to the stimulus (only interruption of the infrared light beam behind the opening was recorded), the natural contingency built into the procedure was that the haptic sensation of a smooth surface would become a discriminative stimulus for selecting the left lever, and the sensation of a rough surface a stimulus for selecting the right lever.

Olfactory discrimination. Rats 3 and 4 were used for olfactory discrimination. The procedure followed the same outline as for tactile discrimination. Shaping of inserting the nose into the hole on the back wall was accomplished in less than five trials, and the rats were spontaneously sniffing at the olfactory stimulus. As described for tactile discrimination, shaping used onset of the light over one of the levers as the reinforcer during shaping. For one session, the tone and only the light above the correct lever turned on after the infrared beam behind the port had been interrupted by the rat's nose for 0.1 s. Thereafter, both lights plus the tone turned on after the sampling response. The only stimulus that indicated which lever was correct was the olfactory stimulus. Thus, even though the equipment did not detect actual sniffing of the stimulus (only interruption of the infrared light beam behind the port was recorded), the contingency built into the procedure was that sensation of the scent of fruit tea would become a discriminative stimulus for selecting the left lever and the scent of British tea a stimulus for selecting the right lever. Some minor adjustments of the olfactory stimulus delivery apparatus took place within the first 10 training sessions, and only the final apparatus version is described here.

A correction procedure was enacted in each session with actual discrimination such that when a trial had an incorrect lever selection, the same stimulus would be repeated on the next trial. Thus, after an incorrect lever press, the motor would make a one quarter turn and present the other stimulus from the pair of identical stimuli.

For both types of discrimination, each session ended after 60 reinforced trials. Training continued for each rat until six consecutive sessions had at least 90% correct selections. Because the experiment was conducted tabletop for visual inspection of the performance of the apparatus during sessions, the possibility existed that potential differential visual cues from the stimulus-delivery unit, especially for the tactile discrimination, might come to function as discriminative stimuli. To determine if visual cues from the stimulus delivery apparatus participated in the tactile or olfactory discriminations, the experimenter turned off all lights in the laboratory, leaving the room totally dark, for the middle 20 trials during two sessions for each rat after accuracy had reached 90% for both types of discrimination. Thus, a within-session ABA design was used to determine whether visual components of the olfactory or tactile stimuli controlled the discrimination.

RESULTS

All rats easily acquired the stimulus-sampling response and oriented to the port on the back wall within a few seconds after motor rotation. Figure 5 shows pictures of the two types of stimulus sampling, touching the disk surface with one paw for tactile discrimination (A) and sniffing at the pod for odor discrimination (B). Notice how the nose practically touches the front mesh of the odor pod. The 2 rats with tactile discrimination always touched the surface on the disk even though a touch on the disk was not necessary to break the infrared beam. Obtaining the haptic sensation from the touch was necessary for the rat to be exposed to the discriminative stimulus presented on a given trial. Hence, the rats always touched the surface of the disk. For the 2 rats with olfactory discrimination, motion of the nostrils was clearly visible to the human observer when the nose was inserted in the port. Thus, all rats initiated trials by actively engaging in a stimulus-sampling response that brought them into contact with the discriminative stimulus presented on that trial.

All rats acquired the two-choice discrimination task. Figure 6 shows percent correct for each rat and session. The two tactile-discrimination rats reached the criterion of six consecutive sessions with 90% or higher within 19 (Rat 1) and 21 (Rat 2) sessions. The two olfactory-discrimination rats reached the criterion within 29 (Rat 3) and 32 (Rat 4) sessions. The online supplementary material (see author's note) features a 30-s video clip of Rat 4 performing a few trials of the olfactory discrimination.

A

B

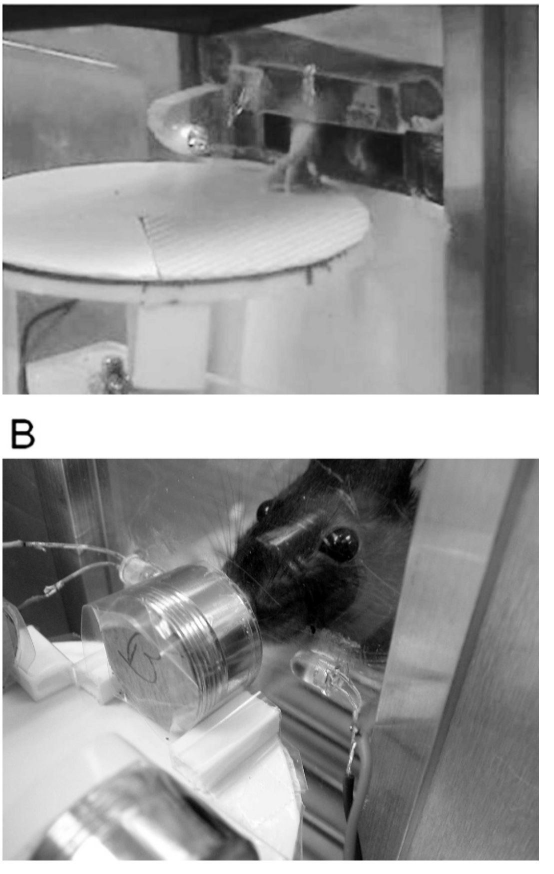

Fig. 5. Photographs of the two types of sampling response. For tactile discrimination, the rat extends a paw through the 4 × 1-cm opening in the back wall and touches the surface of the disk. The paw breaks the beam of an infrared LED located 1 cm from the back wall, and the corresponding phototransistor (not visible on the image) is connected to the computer's parallel port as an input (A). For olfactory discrimination, the rat places the nose in the 1-cm hole in the back wall and sniffs at the olfactory stimulus presented in the aerator (cylinder on the image). The nose breaks the beam of an infrared LED located behind the back wall, and the corresponding phototransistor is connected to the computer's parallel port as an input (B).

During the two test sessions in which the ambient lights in the laboratory were turned off during the middle 20 trials, the rats

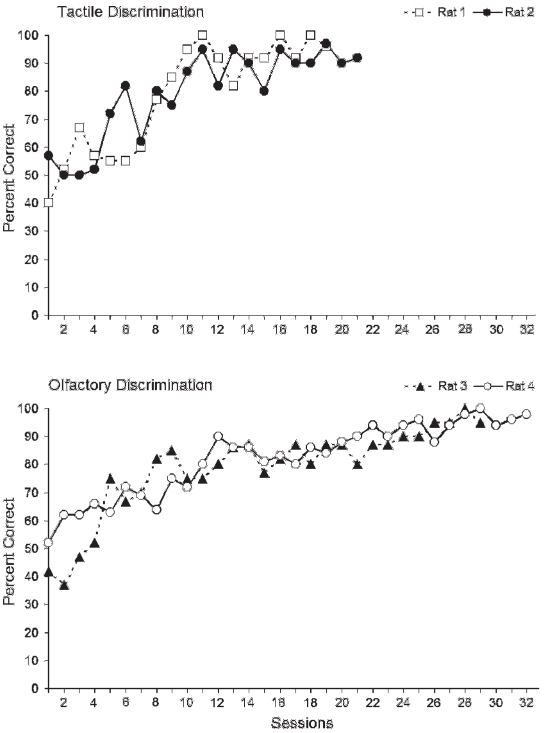

Fig. 6. Percent correct across sessions for each rat and task. Data are for the condition when both lights above the levers lit up after the stimulus-sampling response. Each rat was trained to a criterion of six consecutive sessions with 90% correct or higher.

continued to perform at high accuracy during the light-off period as shown in Table 1, which gives the percent correct for each rat and test session before, during, and after the light-off period. The overall percent correct for all rats were 93.1, 95.0 and 96.4 for the A1, B, and A2 periods. These data demonstrate that visual cues played no role in the discriminations.

DISCUSSION

The fully computerized stimulus-presentation apparatus operated flawlessly. The equipment was fairly simple to construct from a bidirectional motor, infrared detectors, optical relays, faucet aerators, textured plastic sheets, and lab scrap material. The total price for the stimulus-presentation unit was about $150, October, 2007 (excluding test chamber, pellet feeder, and computer). Because the computer's parallel port was used for equipment control, an interface board was not required (see also Iversen, 2002). A simple custom-made logic board with four optical relays was necessary, however, for the control of the direction of motor rotation. Operation of the equipment did require a computer program that read the inputs and controlled the outputs; this was accomplished with a custom-made program using the QuickBasic language. The control of the direction of motor rotation was fairly simple because the program kept track of which quarter of the disk faced the stimulus-sampling port on each trial.

The tactile stimuli were flat surfaces, and the discrimination was between a plain surface and a surface with an embossed pattern. The stimulus-presentation unit could easily be outfitted with other types of surfaces or with small objects, for example a sphere versus a cube, that are fixed to the disk. The olfactory stimuli were based on odors emitted from solid objects (i.e., two types of tea leaves) as opposed to airborne odors pumped to the subject. The stimulus-presentation unit could potentially present the odor of any solid object simply by replacing the content of the odor pods. Because the pods are closed except for the

Table 1

Percent correct for two test sessions with all ambient light turned off. Each session had three periods: A1 (lights ON), the first 20 trials; B (lights OFF), the next 20 trials; A2 (lights ON), the remaining trials in a session. Tests were conducted on sessions 17 and 18 for Rat 1, 18 and 19 for Rat 2, 27 and 28 for Rat 3, and 30 and 31 for Rat 4.

	A1		B		A2	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Rat 1	90	100	95	100	93	100
Rat 2	85	95	90	95	92	97
Rat 3	95	95	95	100	97	100
Rat 4	90	95	90	95	96	96

mesh through which the subjects sample the odor, and because the pods are located behind the back wall, there is only negligible, if any, spread of odor beyond the front-mesh surface of the pod. Because of these features of odor presentation, the apparatus did not require special ventilation or odor cleanout between trials, which has been a necessary requirement for odor presentation equipment that uses airborne odors, as described earlier.

The present experiment was performed tabletop to enable visual inspection of the apparatus during sessions. Although no evidence was found of an influence of visual cues during test sessions, experiments using this type of equipment should ideally be conducted in darkness, at least during the stimulus-sampling period, to avoid any possible differential visual elements from either the odor pods, which is highly unlikely given that they are physically identical on the outside, or the tactile stimuli, which obviously do differ in visual characteristics.

The tactile discrimination was acquired somewhat faster than the olfactory discrimination in the present experiment. With only 2 rats and two stimuli for each type of discrimination, a conclusion cannot be drawn that tactile discrimination in general is acquired faster than olfactory discrimination. However, the apparatus should be ideal for research that compares acquisition of discrimination using stimuli from different modalities if the number of stimulus exemplars were to be increased. One could compare acquisition of discrimination of a variety of odor pairs or pairs of tactile stimuli. Similarly, one could compare the effects of repeated acquisition across discriminations and the possible formation of learning sets, which apparently is a controversial research topic with rats as subjects (e.g., Reid & Morris, 1992; Slotnick, Hanford, & Hodos, 2000).

With the present method, the subject is not passively exposed to the discriminative stimuli as is customarily the case with visual, auditory, and some uses of olfactory stimuli where the stimuli flood the chamber regardless of the subject's location and behavior (e.g., Cohn & Weiss, 2007). The present method used a stimulus-sampling port through which the subject actively seeks contact with the stimulus, and the stimulus is therefore only available to the subject during sampling. The stimulus-sampling response also functions as a trial-initiation response, which in essence enables the subject to set the pace of the trials. Such different methods of subject-sampled versus subject-independent stimulus presentation have not been investigated systematically but may provide very different results (e.g., Iversen, 1998). The present procedure of using a stimulus-sampling response could easily be modified so that it instead presents visual or auditory stimuli only when a subject makes a sampling response such as, for example, placing the nose in a sampling port. A visual stimulus, such as steady versus blinking light, might then be presented right in front of the subject while the subject engages the stimulus-sampling port. Similarly, one of two tones could be presented only while the subject engages the port. Thus, with only minor modifications, the stimulus-presentation apparatus and general method described here could be used for comparisons of acquisition of discriminations in four modalities: visual, auditory, tactile, and olfactory.

Because only two different stimuli can be presented during a session, the present method is of no use for research topics that would require within-session presentation of a variety of stimuli such as is needed for research on stimulus generalization or psychophysics. Without modification, the method is also of no use for research where a delay is to be inserted between stimulus and response or for research where the intertrial interval is a variable. However, one can envision some possible equipment modification that would allow varying stimulus-response delays and intertrial intervals with the present stimulus-delivery apparatus. One such modification could be the placement of the stimulus-sampling port behind a guillotine door that could be locked during a delay or intertrial interval.

The method presented here could also be of use for research on matching to sample or cross-modal discrimination. Figure 7 shows a sketch of a possible application that uses three stimulus-presentation units to enable a matching-to-sample design. One unit, on a back wall, presents the sample stimulus while two other units, on a front wall, present the comparison stimuli. The subject first samples the sample stimulus, and then has to sample the comparison stimuli (at least one of them) and then make a selection response to an operandum

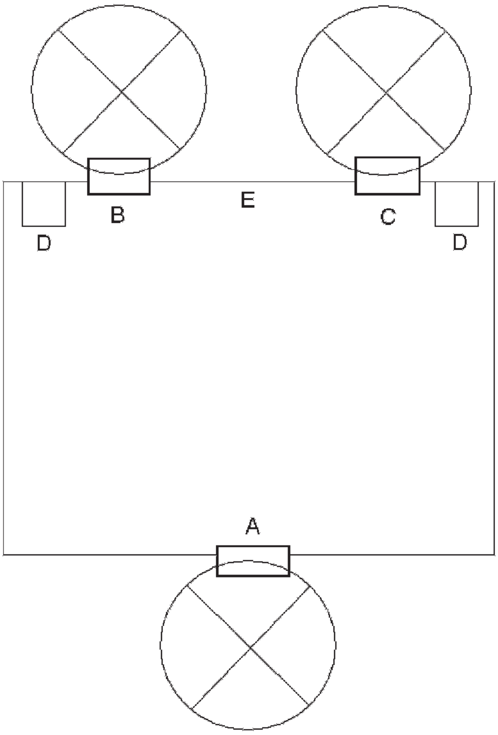

Fig. 7. Schematic of a possible implementation of the automated stimulus-presentation apparatus for matching-to-sample or cross-modal discrimination experiments. A sample stimulus may be presented behind a port on the back wall (A), and the comparison stimuli (B and C) may be presented in ports on the front wall. For all stimuli, the subject samples the stimulus before a response can be made. A possible selection response of comparison stimuli could be a press on a lever next to the stimulus-sampling port (D). Reinforcer delivery could be arranged between the two stimulus-presentation devices on the front wall (E). The schematic is conceptual and not to scale.

that could be located next to a comparison stimulus-sampling port. For example, the matching-to-sample method could be with stimuli from one modality, such as olfactory identity matching or tactile identity matching. The apparatus could also be suited for cross-modal matching with a sample from one modality (e.g., olfactory) and comparison stimuli from another modality (e.g., tactile). Obviously, having three stimulus-presentation units attached to the same test chamber requires some elaboration of the present method and of the programming involved in controlling the equipment. However, such an extension is entirely feasible given the demonstrated reliability of the present method.

REFERENCES

Abraham, N. M., Spors, H., Carleton, A., Margrie, T. W., Kuner, T., & Schaefer, A. T. (2004). Maintaining accuracy at the expense of speed: Stimulus similarity defines odor discrimination time in mice. *Neuron*, *44*, 865–876.

Ballermann, M., Tompkins, G., & Whishaw, I. Q. (2000). Skilled forelimb reaching for pasta guided by tactile input in the rat as measured by accuracy, spatial adjustments, and force. *Behavioural Brain Resarch*, *109*, 49–57.

Cohn, S. I., & Weiss, S. J. (2007). Stimulus control and compounding with ambient odor as a discriminative stimulus on a free-operant baseline. *Journal of the Experimental Analysis of Behavior*, *87*, 261–273.

Domjan, M., Miller, V., & Gemberling, G. A. (1982). Note an aversion learning to the shape of food by monkeys. *Journal of the Experimental Analysis of Behavior*, *38*, 87–91.

Dougherty, D. M., & Lewis, P. (1993). Generalization of a tactile stimulus in horses. *Journal of the Experimental Analysis of Behavior*, *59*, 521–528.

Gleeson, S. (1991). Response acquisition. In I. H. Iversen & K. A. Lattal (Eds.), *Techniques in the behavioral and neural sciences: Experimental analysis of behavior* (Part 1, pp. 63–86). Amsterdam: Elsevier.

Henton, W. W. (1969). Conditioned suppression to odorous stimuli in pigeons. *Journal of the Experimental Analysis of Behavior*, *12*, 175–185.

Henton, W. W., & Iversen, I. H. (1978). *Classical conditioning and operant conditioning: A response pattern analysis*. New York: Springer Verlag, Inc.

Iversen, I. H. (1998). Simple and conditional visual discrimination with wheel running as reinforcement in rats. *Journal of the Experimental Analysis of Behavior*, *70*, 103–121.

Iversen, I. H. (2002). Response-initiated imaging of operant behavior using a digital camera. *Journal of the Experimental Analysis of Behavior*, *77*, 283–300.

Krupa, D. J., Wiest, M. C., Shuler, M. G., Laubach, M., & Nicolelis, M. A. L. (2004). Layer-specific somatosensory cortical activation during active tactile discrimination. *Science*, *304*, 1989–1992.

Lionello-DeNolf, K. M., & Mihalick, S. M. (2006). An automated olfactory discrimination procedure with rats. *The Behavior Analyst Today*, *7*, 560–571.

Lu, X. C. M., Slotnick, B. M., & Silberberg, A. M. (1993). Odor matching and odor memory in the rat. *Physiology and Behavior*, *53*, 795–804.

Mihalick, S. M., Langlois, J. C., Krienke, J. D., & Dube, W. V. (2000). An olfactory discrimination procedure for mice. *Journal of the Experimental Analysis of Behavior*, *73*, 305–318.

Neill, J. C., & Harrison, J. M. (1987). Auditory discrimination: The Kornorski quality-location effect. *Journal of the Experimental Analysis of Behavior*, *48*, 81–95.

Reid, I. C., & Morris, R. G. M. (1992). Smells are no surer: Rapid improvement in olfactory discrimination is not due to the acquisition of a learning set. *Proceedings of the Royal Society of London: Biological Sciences*, *247*, 137–143.

Slotnick, B., Hanford, L., & Hodos, W. (2000). Can rats acquire an olfactory learning set? *Journal of Experimental Psychology: Animal Behavior Processes*, *26*, 399–415.

Slotnick, B. M., & Katz, H. M. (1974). Olfactory learning-set formation in rats. *Science*, *185*, 796–798.
Skinner, B. F. (1938). *The behavior of organisms: An experimental analysis*. New York: Appleton-Century-Crofts.
Sokolic, L., & McGregor, I. S. (2007). Benzodiazepines impair the acquisition and reversal of olfactory go/no-go discriminations in rats. *Behavioral Neuroscience*, *121*, 527–534.
Xerri, C., Bourgeon, S., & Coq, J. O. (2005). Perceptual context-dependent remodeling of the forepaw map in the SI cortex of rats trained on tactile discrimination. *Behavioural Brain Research*, *162*, 207–221.

Received: October 10, 2007
Final Acceptance: March 19, 2008